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AN ELECTRON-MICROSCOPICAL STUDY OF THE TEMPERING OF TUNGSTEN-HIGH SPEED STEELS

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AN ELECTRON-MICROSCOPICAL STUDY OF THE TEMPERING OF TUNGSTEN-HIGH SPEED STEELS*

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Abstract

An investigation into the tempering process of tungsten high speed tool steels has been carried out using optical and electron microscopy. The secondary hardening phenomenon in these steels is caused mainly by the precipitation of W_2C carbides. $M_{23}C_6$ carbide also appears at and above 550°C but does not play a major role in secondary hardening.

Introduction

The phenomenon of secondary hardening in vanadium[1-4] and molybdenum steels[5-7] has been thoroughly studied by previous workers, and it has been established that the secondary hardening in such steels is caused by the precipitation of V_4C_3 and/or Mo_2C. It has also been shown that the precipitation of W_2C leads to secondary hardening in Fe-W-C alloys[8] and also in Fe-W-Cr-C alloys[9]. It is now accepted that such alloy-carbides bring about a strengthening by precipitating as fine particles either on the dislocations or within the matrix coherently.

Although the secondary hardening is a well-known phenomenon in tungsten-high speed tool steels, it has, prior to now, not been studied in detail by electron microscopy. Previous studies were mainly x-ray studies of the electrolytically extracted carbides precipitated during tempering. Such studies[10-13] proved the existence of W_2C carbide in tungsten-high speed steels. However, the results of these studies are not exactly unanimous: e.g. Goldschmidt[10] found that the secondary hardening in tungsten high speed tool steels is caused by what he calls a transition T-carbide. Others[14] maintain that the precipitation of $M_{23}C_6$ in the martensitic matrix is the cause of secondary hardening in these steels.

It is therefore quite clear that the phenomenon of secondary hardening in tungsten high speed tool steels has not been yet fully explained. The object of the present research was to investigate the cause of secondary hardening in these steels chiefly by means of electron microscopy.

Experimental Procedure

The alloy chosen was a standard T-1 steel obtained in the form of 10" long bars of 1" diameter. 0.5 cm thick specimens were cut from the bars and austenitized at 1300°C for 1 hr. under an argon atmosphere.

After quenching into water, specimens were tempered at various temperatures in the range 450°C - 700°C for 1 to 50 hrs.

The isothermal variation in hardness was measured and the structural changes were investigated by extraction and plastic replicas. Thin foil microscopy is now being pursued.

Results and Discussion

The softening of the as-quenched structure ends at about 450°C, and tempering above this temperature leads to secondary hardening which reaches its maximum value, after 8 hours, at 500°C or after 4 hours, at 550°C. Above 550°C the effect of secondary hardening is gradually lost.

In Fig. 1 the microstructures of the as-quenched and overaged specimens are compared. The white patches are the undissolved M_6C carbides which do not undergo a transformation during tempering. It should be noted that the matrix is completely changed and the martensitic structure has been destroyed in the overaged structure.

Differential etching techniques[15-16] revealed the presence of only M_6C carbides in the as-quenched structures. Electron diffraction patterns such as that shown in Fig. 2 provide the same conclusion. These differential etching techniques indicated, furthermore, that these undissolved M_6C carbides do not undergo any transformation during tempering, but, rather, that certain precipitation occurs within the matrix (Fig. 3). This becomes even more obvious when the microstructures are examined at higher magnifications in the electron microscope. In Fig. 4 precipitation on a fine-scale is illustrated. Similarly, plastic-replica electron micrographs also illustrate (Fig. 5) precipitation of a new phase.

During tempering at temperatures above 450°C cementite is the first carbide to precipitate and is observed for tempering up to 550°C. The microstructure resulting from such tempering treatments is illustrated by Fig. 6.

At and above 500°C a new carbide identified as W_2C - begins to appear on a fine scale. The W_2C carbide particles usually seem to be "associated" with the cementite laths which indicates that W_2C might form from cementite by

means of an in-situ transformation. Fig. 7 is comprised of bright and dark field photomicrographs of cementite and W_2C precipitates. The dark-field photograph was taken using a W_2C reflection.

As the appearance of W_2C carbide corresponds to the maximum in the secondary hardening curve it can be concluded that it is the W_2C precipitation that is responsible for the secondary hardening phenomenon in tungsten high speed tool steels.

At 550°C and above another carbide also appears; this is the $M_{23}C_6$ carbide (Fig. 8). This temperature is within that temperature range in which the retained austenite transforms in both tungsten-high speed tool steels[17] and also in Fe-W-Cr-C alloys[9]. It may therefore be expected that $M_{23}C_6$ carbides precipitate not only from the retained austenite but within the martensitic matrix as well - thus causing a limited amount of precipitation hardening. However, as the retained austenite in these steels is no more than 20%, the effect of this precipitation on the overall secondary hardening will be relatively small.

The overaged structures, i.e. specimens tempered at 650° or above, occasionally show V_4C_3 and new M_6C carbides, neither of which plays any important role in the secondary hardening.

Conclusions

During the tempering of the tungsten-high speed tool steels:

1) Maximum secondary hardening occurs after tempering at 500°C for 8 hrs. or at 550°C for 4 hrs.

2) Fe_3C precipitates first and is seen up to 550°C.

3) At 500°C and above W_2C precipitates appear.

4) The secondary hardening is mainly caused by the precipitation of W_2C carbides.

5) W_2C carbides seem to form from cementite with an in-situ transformation.

6) At 550°C $M_{23}C_6$ precipitation starts which occur both from the retained austenite as well as within the martensitic matrix.

7) Softening starts above 600°C.

8) V_4C_3 and new M_6C carbides also appear in the overaged structures.

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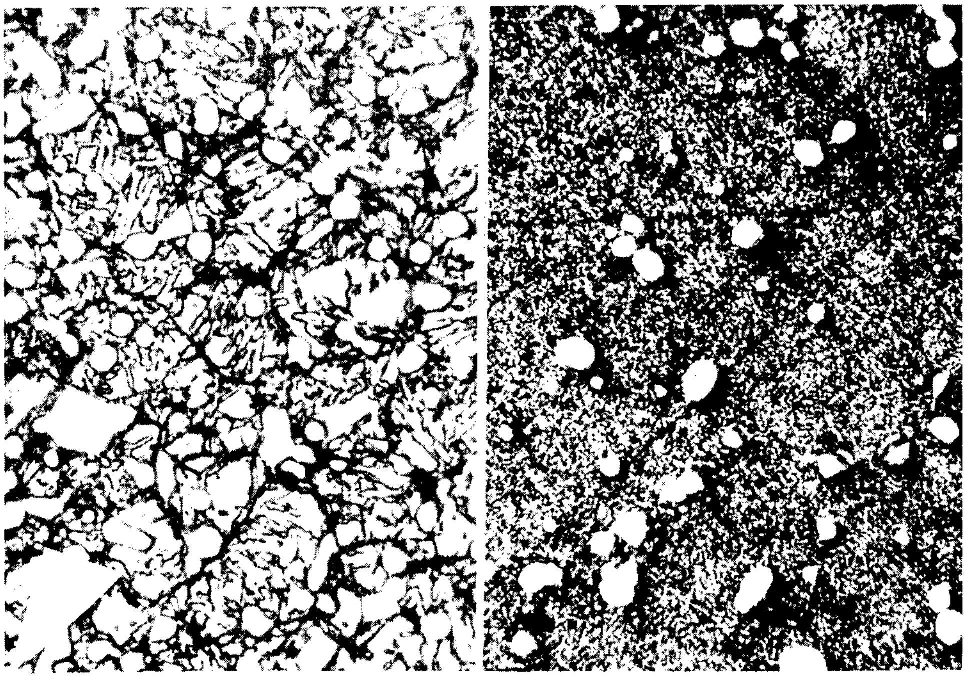

FIG. - 1

The microstructures of the as-quenched and overaged ($700^{o}C$/10 hrs.) 18-4-1 steel 3% Nital - 1200 X.

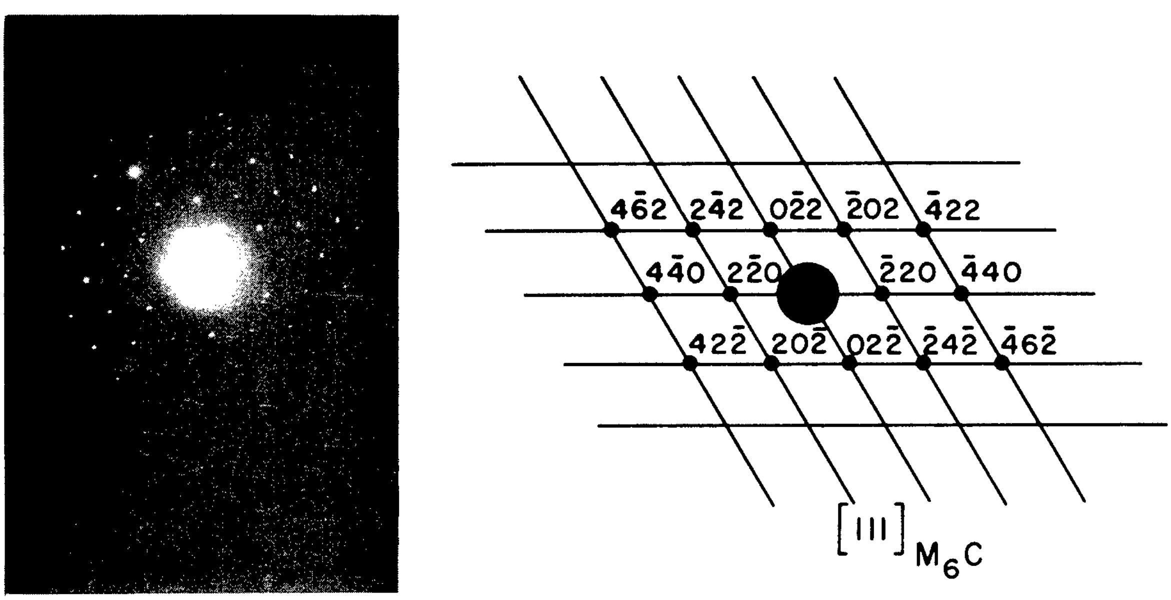

FIG. - 2

Electron diffraction photograph of an undissolved M_6C carbide extracted from the as-quenched structure.

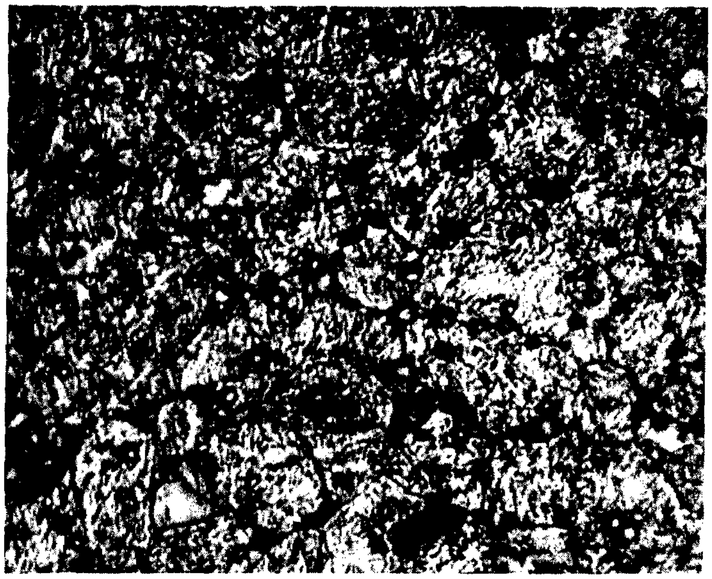

FIG. - 3

The microstructure of 18-4-1 steel tempered at 500°C for 2 hrs. - differentially etched - 1000X.

FIG. - 4

Plastic replica micrograph of 18-4-1 steel tempered at 500°C for 40 hrs. - 8000 X.

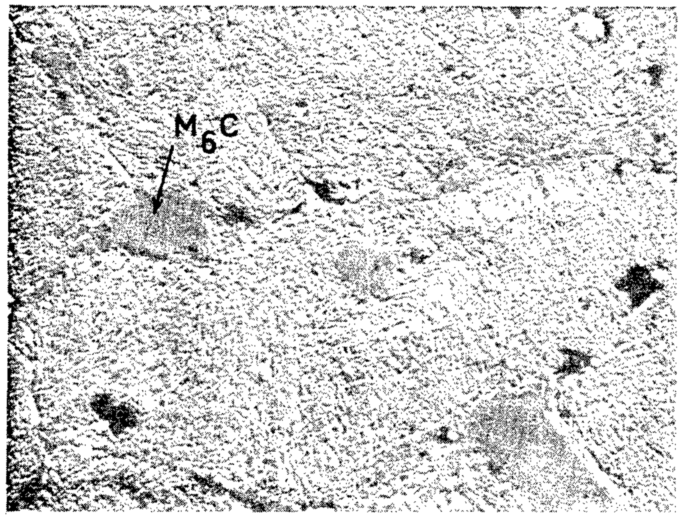

FIG. - 5

Plastic replica micrograph of 18-4-1 steel tempered at 600°C for 6 hrs. - 8000 X.

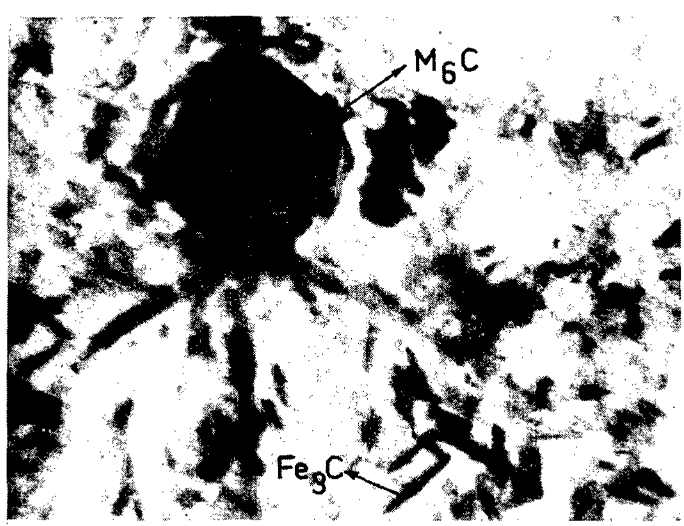

FIG. - 6

Existence of M_6C + Fe_3C extracted from 18-4-1 steel tempered at 500°C for 25 hrs. - 22.500 X.

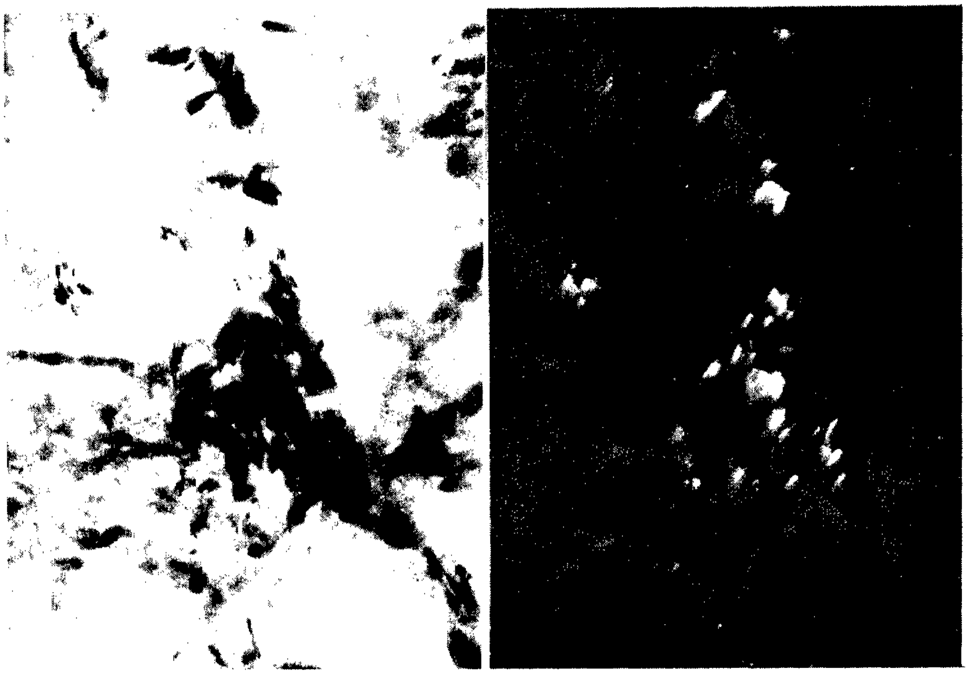

FIG. - 7

Fe_3C and W_2C carbides extracted from 18-4-1 steel tempered at 550°C for 25 hrs. - Dark field photograph was taken using a W_2C reflection - 26,000 X.

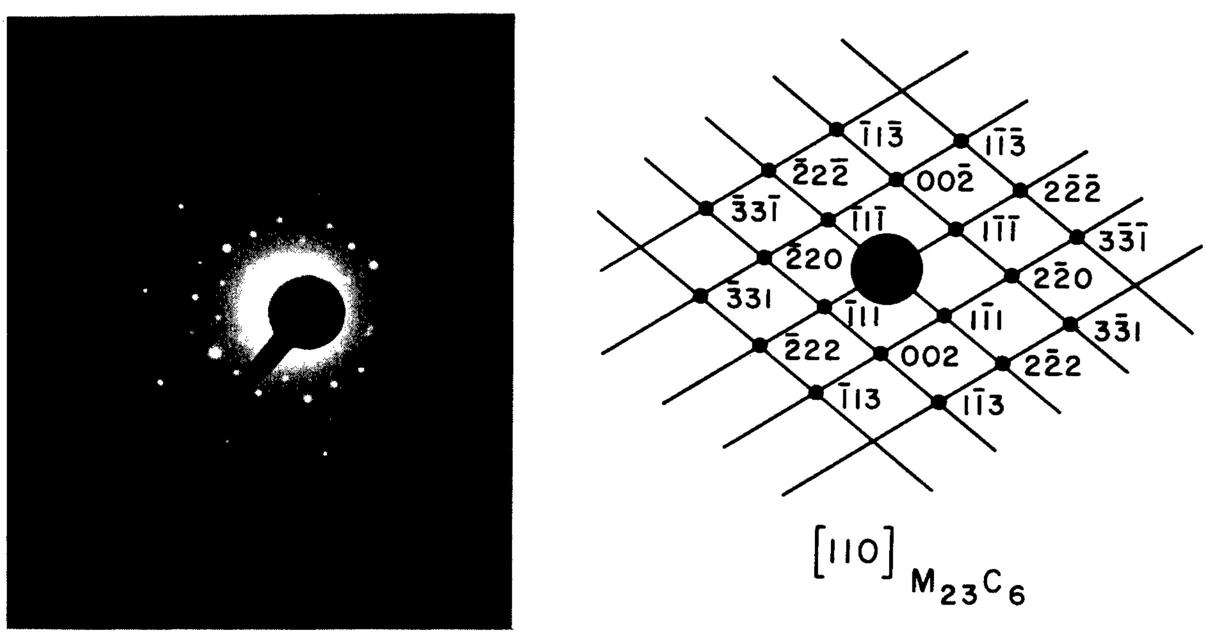

FIG. - 8

Electron diffraction photograph of $M_{23}C_6$ carbide extracted from specimens tempered at 600°C for 50 hrs.

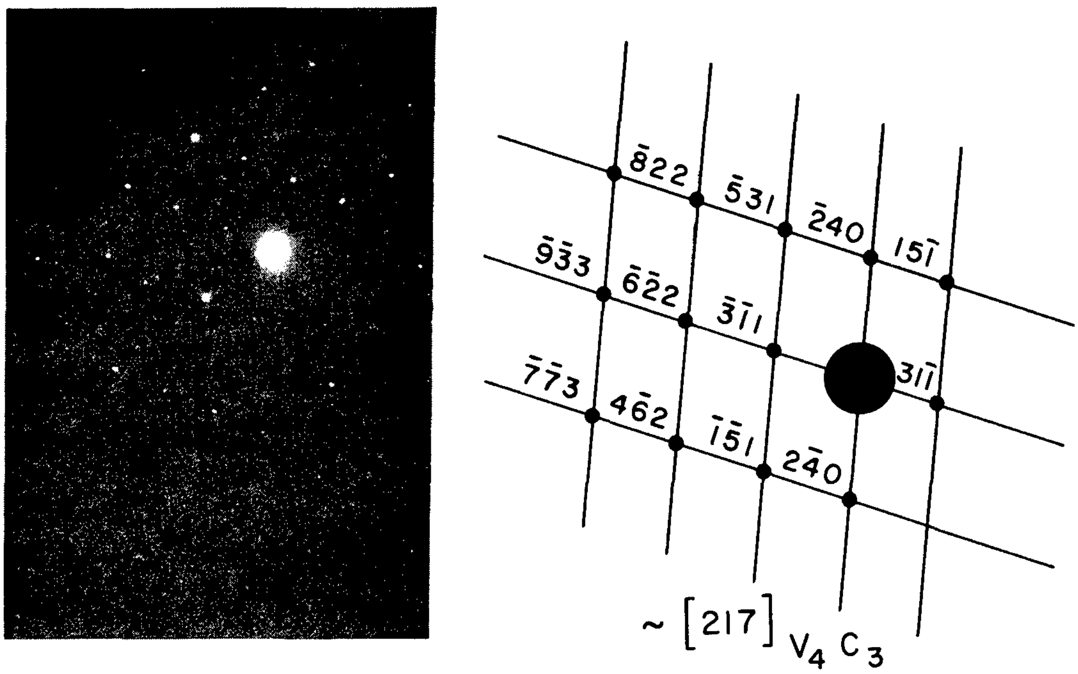

FIG. - 9

Electron diffraction photograph of a V_4C_3 carbide extracted from a specimen tempered at 700°C for 22 hrs.